

Solid Oxide Fuel Cell/GT Hybrid Locomotive

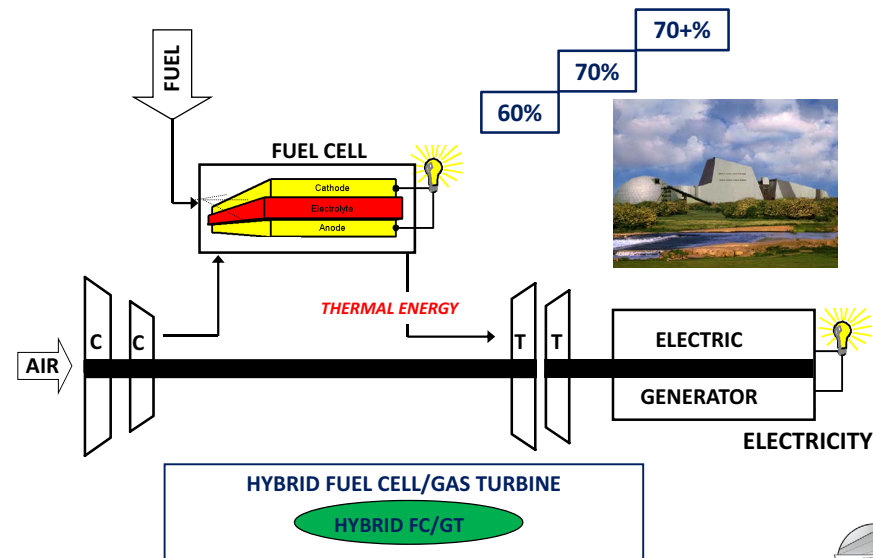
National Fuel Cell Research Center



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April 11, 2013

FUEL CELL/GAS TURBINE HYBRID

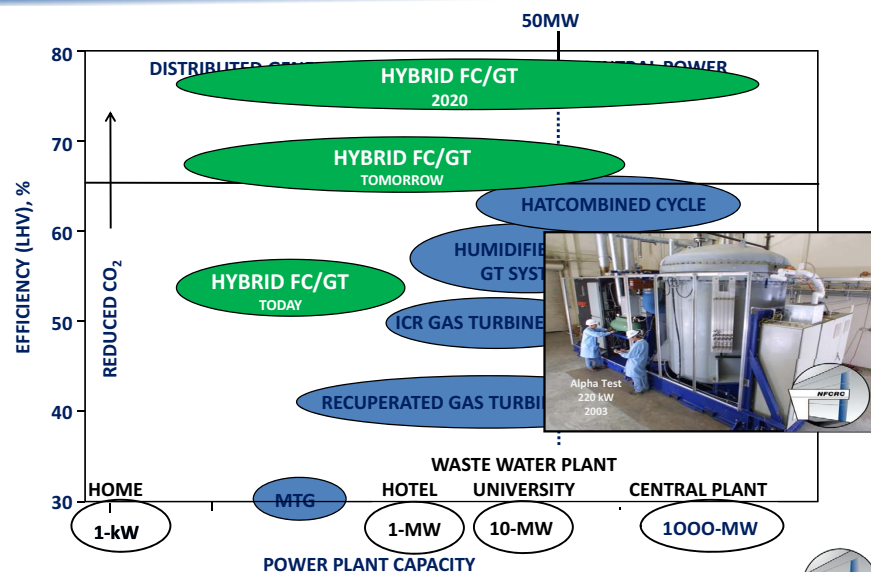


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FUEL CELL/GAS TURBINE HYBRID



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FUEL CELL/GAS TURBINE HYBRID

• Electricity



HYBRID FC/GT

• Locomotives



HYBRID FC/GT

• Ships



HYBRID FC/GT

• Trucks



HYBRID FC/GT

• Aircraft



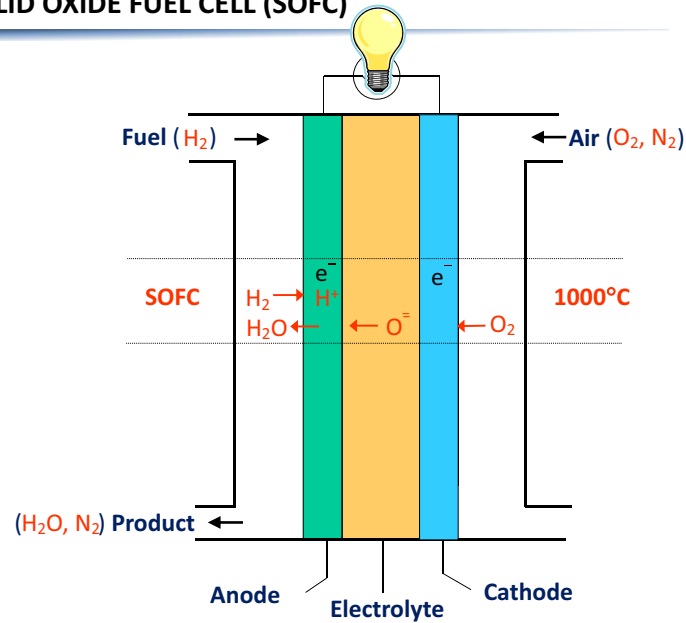
HYBRID FC/GT

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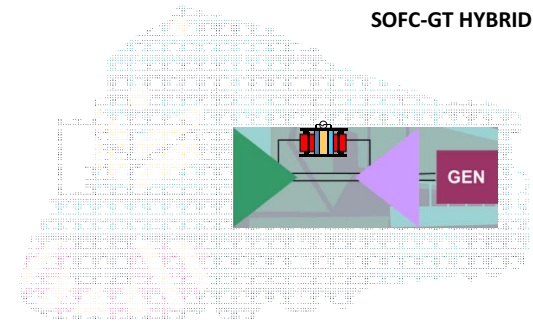
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SOLID OXIDE FUEL CELL (SOFC)



SOLID OXIDE FUEL CELL/GAS TURBINE (SOFC-GT) HYBRID



WHY THE SOFC-GT HYBRID?

- **Diesel-Electric Locomotive Engine**
 - Efficiency less than 30%
 - NO_x and $PM_{2.5}$ Emissions are high
 - Emissions concentrated in areas local to rail operations
- **Diesel-Electric Locomotive Operation**
 - High noise levels onboard and near rail operations
- **SOFC-GT Hybrid Locomotive Engine**
 - Potential to address major concerns associated with diesel-electric
 - Efficiency greater than 60%
 - Virtually-Zero criteria pollutant emission levels
 - Low operating noise levels



MAIN GOALS

- **Determine**
 - The technical feasibility of an SOFC-GT locomotive engine
 - The hurdles, and identify, analyze, and provide solutions
 - Operating requirements for diesel fuel, natural gas, and hydrogen
- **Evaluate**
 - Performance over a demanding, but realistic duty cycle
- **Collaborate**
 - Funding agencies: Air Resources Board, South Coast AQMD
 - Industry: Union Pacific, General Electric



PROPOSED SYSTEM

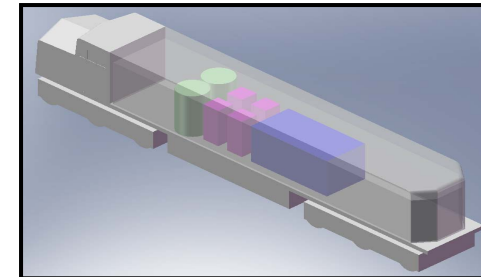


- **Baseline *Diesel-Electric* Locomotive Engine**
 - GE AC4400CW: Previous generation but widely used
 - GE ES44AC: Current state-of-the-art
 - Both 3355 kW of power (4500 hp)
- **SOFC-GT Hybrid Locomotive Engine**
 - SOFC: 3.0 MW
 - GT: 0.5 MW

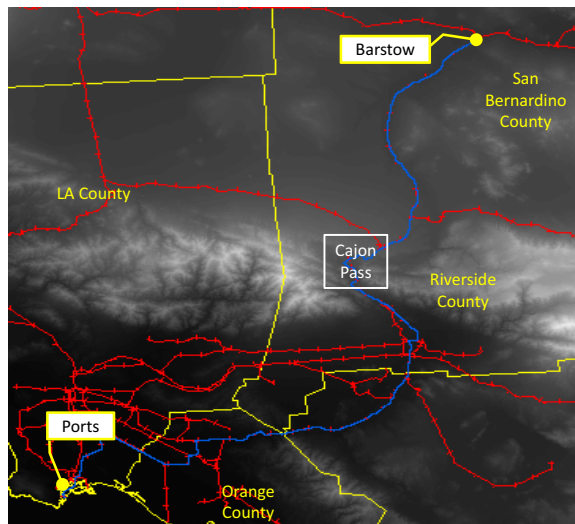


SYSTEM SIZE EVALUATION

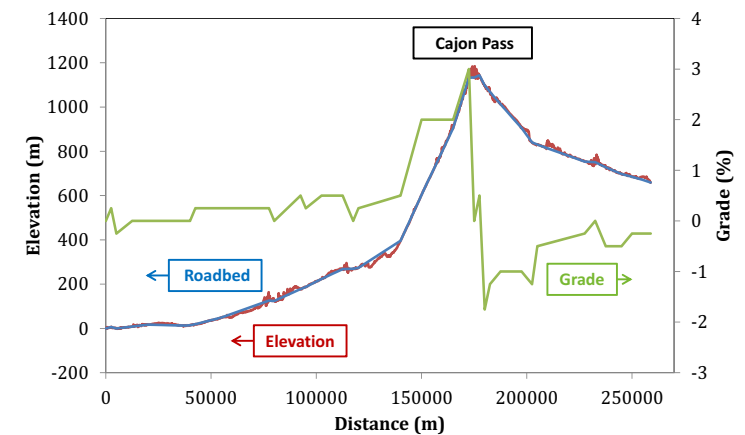
	Footprint (m ²)	Volume (m ³)
Total Diesel-Electric System	~11	~53
SOFC	2.70	13.55
GT	9.02	21.74
Fuel Handling	3.16	7.74
Total SOFC-GT System	14.88	43.03



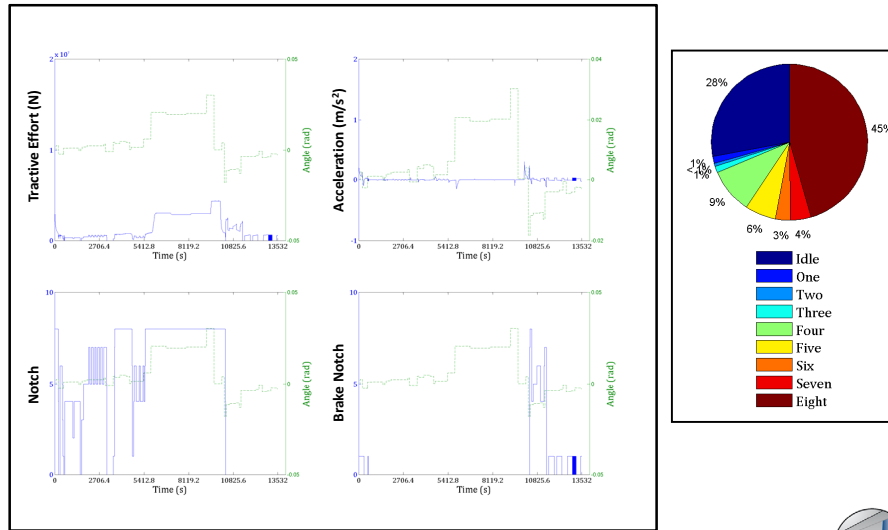
PERFORMANCE



PERFORMANCE



PERFORMANCE



SUMMARY

- SOFC-GT engine fits within the confines of a locomotive
- Diesel-Fuel Powered
 - Average system efficiency: 52%
 - CO₂ reduction: 30.2%
 - NO_x reduction: 97.7%
- Natural Gas-Fuel Powered
 - Average system efficiency: 60%
 - CO₂ reduction: 53.8%
 - NO_x reduction: 97.7%
- Hydrogen-Fuel Powered
 - Average system efficiency: 58%
 - CO₂ reduction: 100%
 - NO_x reduction: 100%



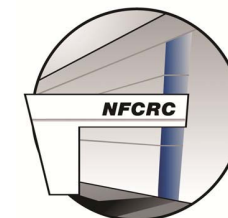
SUMMARY

- State of the technology
 - Proof of concept completed (Phase I)
 - Next step is a prototype test (Phase II)
- Challenges or barriers to commercialization
 - R/D funding to undertake and complete a prototype test (Phase II)
 - R/D funding for component and system optimization (Phase III)
- Timeline for commercialization for the technology
 - Ten years with completion of Phase II and Phase III in a timely fashion



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